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PATENT SPECIFICATION 1,010,023

DRAWINGS ATTACHED.

Date of Application and filing Complete Specification: March 9, 1964. No. 9895/64.

Application made in United States of America (No. 264,384) on March 11, 1963.

Complete Specification Published: Nov. 17, 1965.

1,010,023

Index at Acceptance :—E1 F(5, 7, 44); C5 ED19.
Int. Cl.—E 21 b 43/24 //C 10 b.

COMPLETE SPECIFICATION.

Heating of Underground Formations.

ERRATA

SPECIFICATION NO. 1,010,023

AMENDMENT NO. 1

Page 2, line 55, *for* "in" *read* "into"

Page 2, line 105, *for* "rate" *read* "rates"

THE PATENT OFFICE,
5th May, 1966

D 70671/8

terial from formations containing hydrocarbons or other organic materials, such as coal, in quantities that are not sufficient for combustion to be maintained in the formation by the injection of air or another oxygen containing fluid.

Combustion within a formation requires the presence of a fuel and oxygen in critical proportions at a temperature above a critical minimum. Some formations in which combustion cannot be maintained by the injection of air contain combustible materials or contain substances which produce combustible materials when they are heated, but contain these substances in proportions such that the heat from burning the combustible materials is insufficient, or is too rapidly lost, to maintain a temperature at which ignition occurs.

In oil production processes, especially in the secondary recovery of oil, it is sometimes desirable to move a combustion front through a substantially barren formation, that is, one which will not support combustion, in order to supply heat to an ad-

confined to the general shape of an arc of a circle around the injection well and the region through which the burning zone can be moved is necessarily a generally circular or spherical region of expansion around the injection well.

According to the present invention a method of heating an underground formation in which combustion cannot be maintained by the injection of air alone comprises the steps of:

(a) injecting fuel at one point into the formation,

(b) injecting an oxygen-containing fluid into the formation at a point spaced from the fuel-injection point but within contact range of the injected fuel, wherein the period over which the injection of the oxygen containing fluid takes place at least partly coincides with the period over which the injection of the fuel occurs,

(c) igniting the mixture of fuel and oxygen-containing fluid at least at one point along the contact front where they combine into a combustible mixture, thereby forming

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COMPLETE SPECIFICATION.

Heating of Underground Formations.

We, SHELL INTERNATIONALE RESEARCH MAATSCHAPPIJ N.V., a Company organised under the Laws of the Netherlands, of 30 Carel van Bylandtlaan, The Hague, The Netherlands, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:

This invention relates to the heating of underground formations and is particularly concerned with an in-situ method for thermally fluidizing minerals or hydrocarbons occurring in or near sub-surface formations in which combustion cannot be maintained by the injection of air alone. The present method is especially useful in producing material from formations containing hydrocarbons or other organic materials, such as coal, in quantities that are not sufficient for combustion to be maintained in the formation by the injection of air or another oxygen containing fluid.

Combustion within a formation requires the presence of a fuel and oxygen in critical proportions at a temperature above a critical minimum. Some formations in which combustion cannot be maintained by the injection of air contain combustible materials or contain substances which produce combustible materials when they are heated, but contain these substances in proportions such that the heat from burning the combustible materials is insufficient, or is too rapidly lost, to maintain a temperature at which ignition occurs.

In oil production processes, especially in the secondary recovery of oil, it is sometimes desirable to move a combustion front through a substantially barren formation, that is, one which will not support combustion, in order to supply heat to an adjacent formation. Various methods of supplying both air and fuel to maintain an in-situ combustion in such barren formations have already been proposed.

However, in each of the processes suggested, the fuel and air are injected through the same well, either concurrently as components of a single fluid stream, or sequentially as components of intermittently injected fluids. One drawback to such a procedure is that when combustible materials flowing from the same injection well reach their ignition temperature within a cavern or fissure near the injection well, a back-flashing can occur. This may damage the well. Secondly, in the suggested procedures the pattern of the burning zone is necessarily confined to the general shape of an arc of a circle around the injection well and the region through which the burning zone can be moved is necessarily a generally circular or spherical region of expansion around the injection well.

According to the present invention a method of heating an underground formation in which combustion cannot be maintained by the injection of air alone comprises the steps of:

(a) injecting fuel at one point into the formation,

(b) injecting an oxygen-containing fluid into the formation at a point spaced from the fuel-injection point but within contact range of the injected fuel, wherein the period over which the injection of the oxygen containing fluid takes place at least partly coincides with the period over which the injection of the fuel occurs,

(c) igniting the mixture of fuel and oxygen-containing fluid at least at one point along the contact front where they combine into a combustible mixture, thereby forming

a combustion front which subsequently propagates along the entire contact front,

(d) discharging the products of the combustion from the formation at a point displaced from the points at which the fuel and the oxygen-containing fuel are separately injected, and,

(e) controlling the injection rates of the fuel and the oxygen-containing fluid to maintain the combustion front in a selected area of the formation being heated.

The present invention accordingly provides a method of carrying out in-situ heating within a formation thermally to fluidize minerals or hydrocarbons occurring in a formation, or a selected region thereof, which does not contain enough fuel to support combustion.

The combustion front may be moved as desired within the formation by varying the injection rate of fuel and/or varying the rate of injection of oxygen containing fluid to heat various regions of the formation so as to volatilize minerals contained within the formation or to volatilize or reduce the viscosity of hydrocarbon materials contained within the formation and move them to a production well.

If desired, various regions of the formation may be selectively heated one or more times by means of a moving combustion front which is moved either continuously or in a stepwise fashion through the formation.

The invention may be carried into practice in a number of ways but various embodiments will now be described by way of example with reference to the accompanying drawings in which:—

Figures 1 to 3 are each diagrammatic plan views of three wells with various flow patterns of injected materials being schematically shown extending between the wells;

Figure 4 is a similar plan view of four wells; and

Figure 5 is a diagrammatic view of a pair of wells taken in longitudinal cross-section with the air and fuel flow patterns being schematically shown between the wells.

In Figure 1 a plan view of the preferred arrangement of wells is shown for use in carrying out the method of the present invention. The method is started by injecting a fuel such as methane in the formation to be heated through well number 1 and producing the fluid at well number 3. The several lines forming flow patterns of fuel represent the injection of fuel at successive and increasing flow rates.

After a suitable pattern of flow of fuel from well 1 to well 3 has been established, air or an oxygen-containing fluid is injected through well 2 (Figure 2). If no self-ignition of the fuel occurs, the oxygen-containing fluid is injected through well 2 either simultaneously with or subsequent to the formation temperature of well 2 being raised by means of a suitable down-hole heating device. Alternatively, at the time the air is injected into well 2 with the fuel being present in the adjacent formation, the mixture can be ignited by any suitable ignition procedure, e.g. by utilizing an ignition means which would be lowered into the well to the desired depth. The air injection rate is preferably kept small enough compared to the fuel injection rate so that the fluids produced in well 3 do not constitute an explosive mixture. With a small air injection rate, the regions of contact of the fuel and air are, at least partially within the zone of the formation, heated by any down-hole heater used within well 2. Once ignition has been accomplished, the heater can be turned off and the heat of combustion used to maintain the temperature of the air and fuel above the ignition temperature. The hatched portion 14 shown in Figure 2 represents schematically the combustion front surrounding well 2 and extending to well 3.

The location of the combustion front 14 within the formation can be readily changed by adjusting the air and fuel injection rates. Increasing the injection rate of the air relative to that of the fuel moves the combustion zone further away from well 2 (Figure 3), both in the direction towards well 1 and in the direction normal to a line between wells 1 and 2. A reduction in the fuel injection rate into well 1 will cause the combustion zone to move still further from well 2. An increase in the fuel injection rate into well 1 would have the opposite effect. Simultaneous increase of injection rate of both the fuel into well 1 and the air into well 2 would cause a greater sideward movement of the combustion front, thus allowing the combustion front to sweep into greater areas of the formation under consideration.

By the thermal energy developed within the formation, the materials, such as minerals or hydrocarbons, present in the formation are heated. As far as such materials are capable of being thermally converted to a liquid or gaseous fluid they can be produced from said formation via the production well 3. The combustion products from the front 14 may be produced through the same well 3, or be driven further into the formation or into another formation.

An analysis of the produced gas from well 3 indicates whether combustion is occurring. In the event that combustion within the formation has stopped, the gaseous mixture in the formation can be re-ignited in the manner in which it was originally ignited. The location of the regions in which combustion is occurring within the formation can be deter-

mined by methods well-known to reservoir engineers, such as by calculating the flow paths of the injected gas. Combustion can be maintained within the formation while moving the combustion front from one region to another as long as the injection rates of the fuel and the air are not changed so rapidly that the mixing zone is moved into portions of the formation which have not been previously heated to ignition temperature by the combustion front.

As illustrated in Figure 4, the location of the burning region 14 within the formation can be readily changed by producing the fluids from an additional well 4 for example. By producing from well 4 located to the left of well 1, the burning region 14 can be relocated in a manner shown. The combustion zone can be moved back and forth between the wells as many times as desired. The rate at which the combustion zone can be moved is materially greater than the rates of movement which are possible for combustion zones produced by burning in a matrix containing a static body of fuel.

While the method of the present invention has been described above as being carried out through three wells or conduits in communication between the surface and the underground formation to be heated, it will be appreciated that it is not essential that three sub-surface locations be employed. Thus, as shown in Figure 5, a well 6 is provided with a conduit 7 through which fuel is injected, and a conduit 8 through which oil or other fluid production is produced. The open lower ends of the two conduits 7 and 8 are isolated one from the other by means of a packer 9. Around the well 6 and into the formation 10 there extends a barrier 11 which is either of natural origin or artificially formed, e.g. by injecting a heat-resistant material such as cement, into a fracture extending radially from the well 6. Alternatively, the barrier of a sealing material could be injected without fracturing the formation. The barrier 11 directs the fuel flow 15 into the formation 10 in a manner such as to cause it to sweep a considerable area prior to it being contacted by a flow 16 of air from a conduit 12 positioned in a well 13. Thus a combustion front forms at 14 and may be moved up or down within the formation by varying the flow of the two injected fluids. Thus in the arrangement shown in Figure 5, two of the three sub-surface locations are provided in a single well.

The heat generated within the formation 10 which e.g. consists of a barren sand, is conducted to an overlying formation 17 containing oil or another valuable product which is fluidized by the application of heat. The hot product is produced from the formation 17 by injecting a suitable drive fluid at the top of the well 13 into an annular space 18 from which space it passes into the formation 17 via openings 19 provided in the wall of the well 13. The produced product is removed from formation 17 via openings 20 provided in the wall of well 6, and a conduit 8 to the top of well 6. Equal results will be obtained when injecting the drive fluid through the well 6 into the formation 17 and producing through the well 13. It will be clear that the use of a drive fluid is not required, if gravitational force is found sufficient for the transport of the product to a production well.

The formation heating method described above can also be used in conjunction with the production of any mineral matter capable of being thermally converted to a liquid or gaseous fluid. Various examples of volatilizable contents of sedimentary strata to which the method of the present invention can be applied may be native metals such as mercury, bismuth, antimony, arsenic, zinc, etc., sulphur, both native and in composition, inpyrite, mispickel, galena, redruthite, argentite, blends, etc., chlorides of the metals and alkalis such as calomel, sylvite, chlorite, salmiac, etc., oxides of the metals, such as arsenolite, etc., sulphides of the metals, such as cinnabar etc., inorganic acids in compositions, such as carbonic dioxide etc., and any volatilizable minerals produced by the chemical action upon the constituent of the strata of mineralizing agents.

The process can be used either for heating or for simultaneously thermally fluidizing and fluid driving a material which is present in the formation in which in-situ combustion cannot be maintained by injecting air alone.

In simultaneously thermally fluidizing, fluid driving, and producing a material, the location into which fluids are displaced is maintained at a pressure lower than the injection pressure of the fuel and the air, and the fluidized material is withdrawn along with the fluid combustion products and the fluids displaced from the formation.

The initial permeability of the formation in which the burning is to be conducted is not a limitation. The necessary fluid communication through the formation can be established by hydraulic fracturing, underground explosions or the like. The fissures and caverns in locations in which the fuel-containing and oxygen-containing fluids meet will become filled with explosive mixtures and detonations will occur. Such explosions will convert the nearby portions of the formation to highly porous fragmented portions and the region of this occurrence will be moved along with any movements of the junction of the fuel-containing and oxygen-containing fluids.

In an operation wherein a normally solid material is thermally liquefied and the fluid is driven into a production well, the liquefied material, such as sulphur, must be pumped out or removed in a manner so as to maintain a relatively low pressure in the production well. The present method can be employed to roast an ore, to reduce the viscosity of a liquid or solid which cannot be fluid-driven at the applicable pressures, or to pyrolyze a material into fluid products.

It will be understood that the present invention is not limited to the methods which have been described in connection with Figures 1 to 5 since many modifications may be made.

WHAT WE CLAIM IS:—

1. A method of heating an underground formation in which combustion cannot be maintained by the injection of air alone comprising the steps of:

(a) injecting fuel at one point into the formation,

(b) injecting an oxygen-containing fluid into the formation at a point spaced from the fuel-injection point but within contact range of the injected fuel, wherein the period over which the injection of the oxygen-containing fluid takes place at least partly coincides with the period over which the injection of the fuel occurs,

(c) igniting the mixture of fuel and oxygen-containing fluid at least at one point along the contact front where they combine into a combustible mixture, thereby forming a combustion front which subsequently propagates along the entire contact front,

(d) discharging the products of the combustion from the formation at a point displaced from the points at which the fuel and the oxygen-containing fuel are separately injected, and

(e) controlling the injection rates of the fuel and the oxygen-containing fluid to maintain the combustion front in a selected area of the formation being heated.

2. A method as claimed in claim 1, including the step of heating the formation in the vicinity of the combustion front by the combustion front for a period sufficient to cause at least a portion of an extractible material in the formation to be moved through the formation, and to be discharged from the formation.

3. A method as claimed in claim 1 or claim 2, including the step of varying the injection rate of the fuel to move the combustion front to another area of the formation.

4. A method as claimed in any one of the preceding claims including the step of varying the injection rate of the oxygen-containing fluid to move the combustion front to another area of the formation.

5. A method as claimed in any one of the preceding claims wherein the steps of injecting fuel and of injecting oxygen-containing fluid into the formation take place through separate wells at points spaced from each other and from a production well.

6. A method as claimed in claim 5, wherein the injection wells are both to one side of and substantially in line together with the production well.

7. A method as claimed in claim 1, wherein the steps of injecting fuel and of injecting oxygen-containing fluid take place through separate spaced apart injection wells while the products of combustion are first discharged through a production well to one side of the injection wells and including the steps of subsequently closing the production well and opening another production well through which the products may be discharged substantially on the opposite side of the injection wells.

8. A method as claimed in claim 1, including the step of heating the formation in the vicinity of the combustion front by the combustion front for a period sufficient to heat by thermal conduction part of a second formation adjoining the first formation, thereby causing at least a portion of an extractible material in the second formation to be moved through this formation and discharged therefrom.

9. A method of heating an underground formation, substantially as described herein with reference to Figures 1 to 3 or Figure 4; or Figure 5 of the accompanying drawings.

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Chartered Patent Agents,
Agents for the Applicants.

Abingdon: Printed for Her Majesty's Stationery Office, by Burgess & Son (Abingdon), Ltd.—1965.
Published at The Patent Office, 25 Southampton Buildings, London, W.C.2,
from which copies may be obtained.

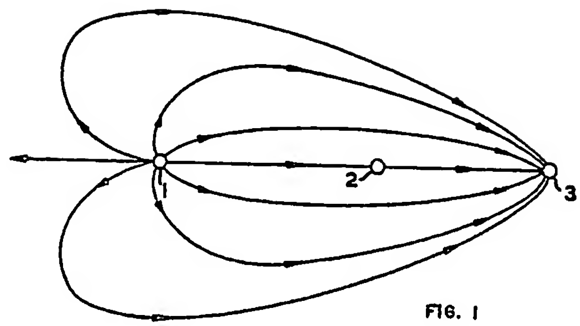

FIG. 1

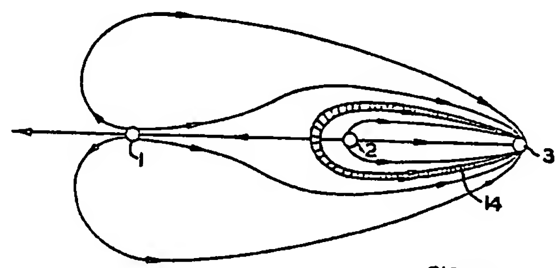

FIG. 2

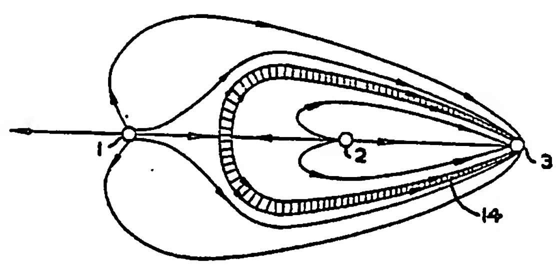

FIG. 3

1010023 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheets 1 & 2

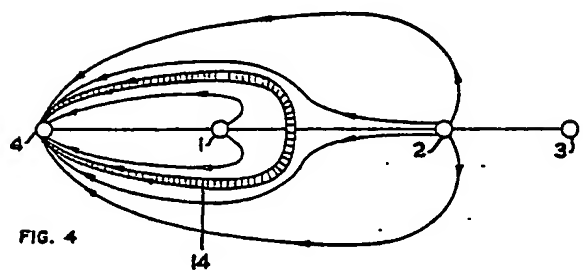

FIG. 4

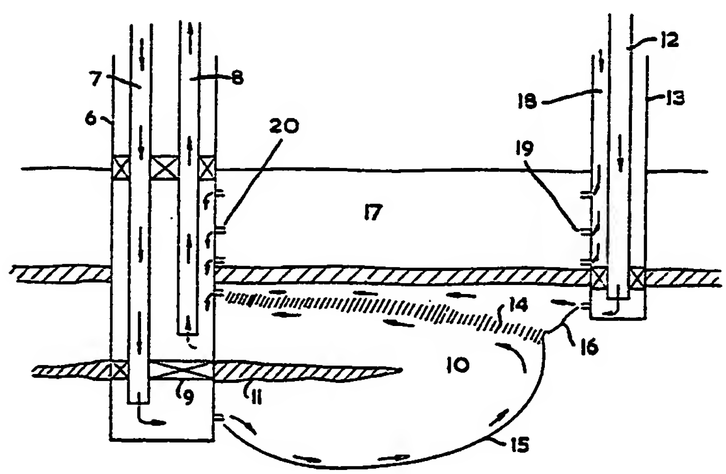

FIG. 5

1010023 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheets 1 & 2

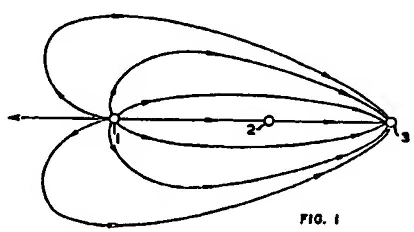

FIG. 1

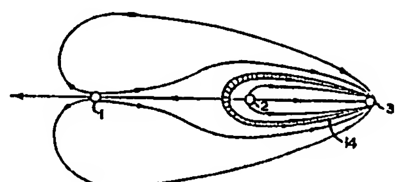

FIG. 2

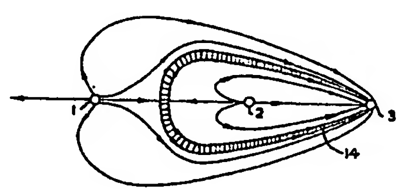

FIG. 3

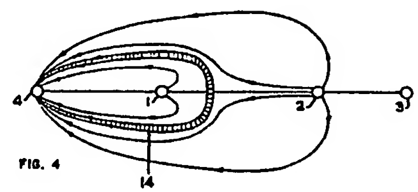

FIG. 4

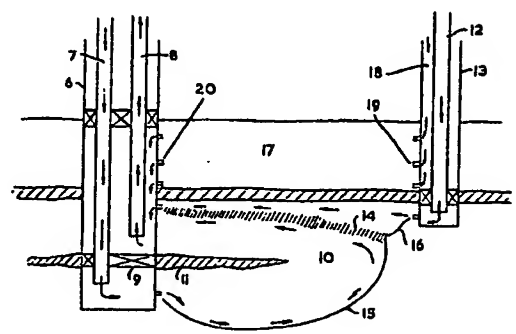

FIG. 5